

ADVANCED MEMS SPATIAL LIGHT MODULATOR FOR COMMUNICATIONS, IMAGING, AND TARGETING

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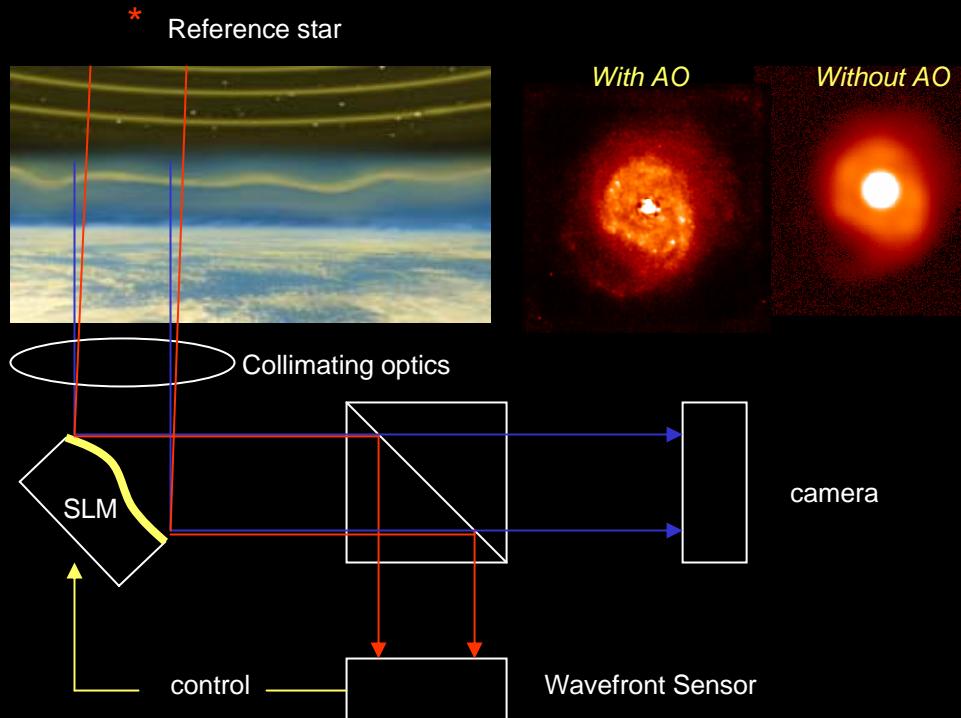
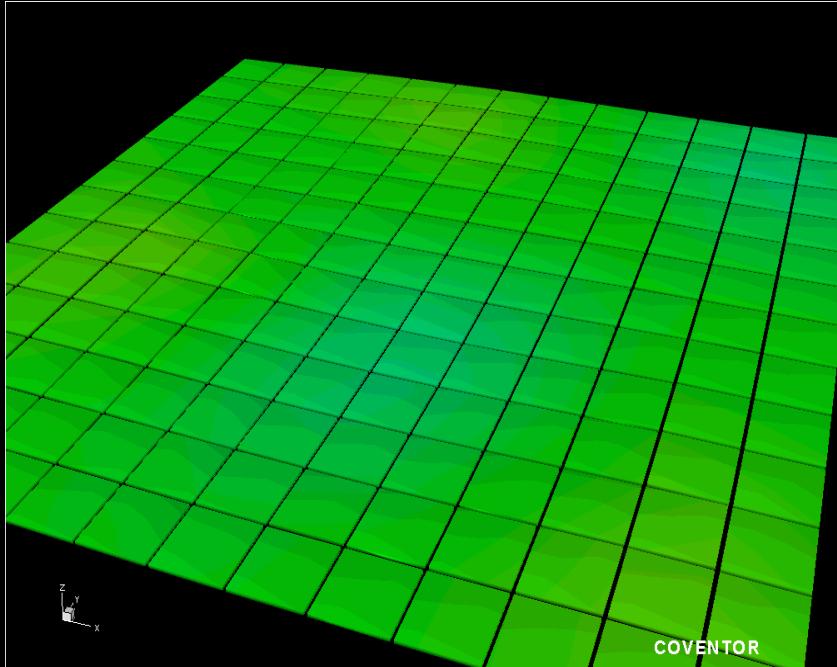
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Lucent Technologies
Bell Labs Innovations

This material is based on work supported in part
by DARPA's CCIT program under contract Number
HR0011-04-C-0048

Advanced pixelated SLMs: Applications



- Imaging
- Optical, secure, free-space communications
- Segmented: Tracking–targeting–scanning



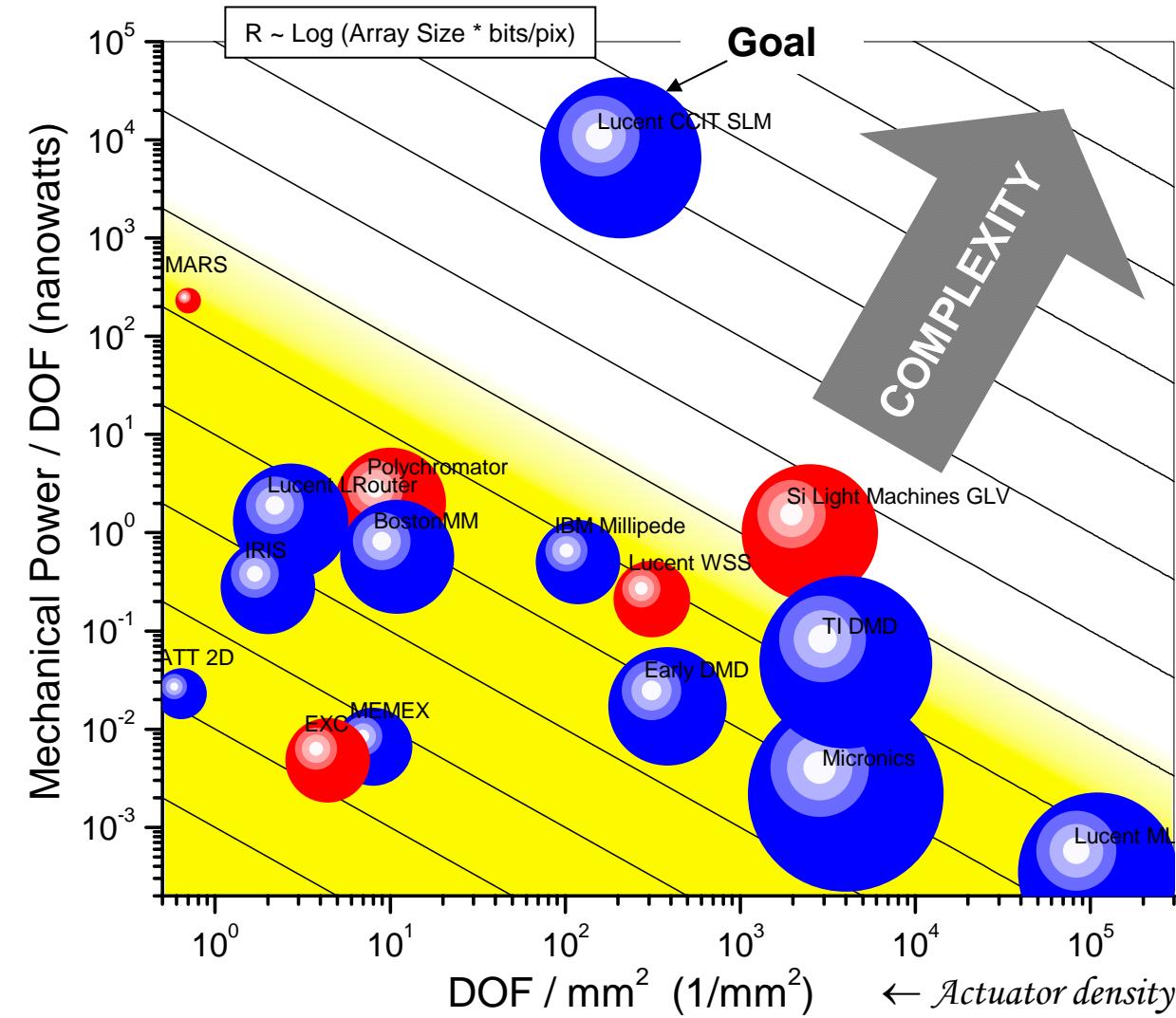
Complex Mirror Array

- LARGE** Tip-tilt, Piston motion
- FAST** Tip-tilt, Piston response time.
- FLAT**, smooth, reflective
- HIGH** Fill factor



Breaking out of the traditional MEMS space...

MEMS arrays complexity map



- Large Mechanical Power
- Fast $\tau^{-3} m \Delta_x^2$
- Large displacement $(\tau^{-3} I \Delta_\Theta^2)$
- Flat (thick) mirror
- $\approx 120\mu\text{m}$ mirror (system, chips size)
- Integrable with electronics, scalable ($\approx 100\text{V}$)
- $64^2, 256^2$ and beyond...
- High fill factor (>98%)
- Flat (30nm, 2nm Roughness)

Array

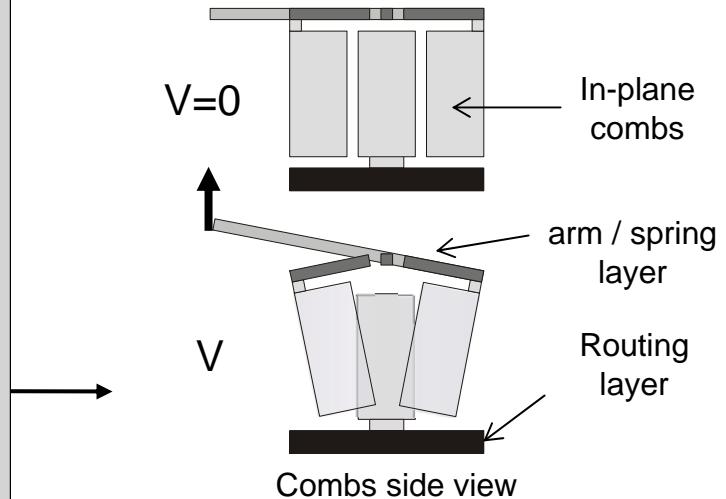
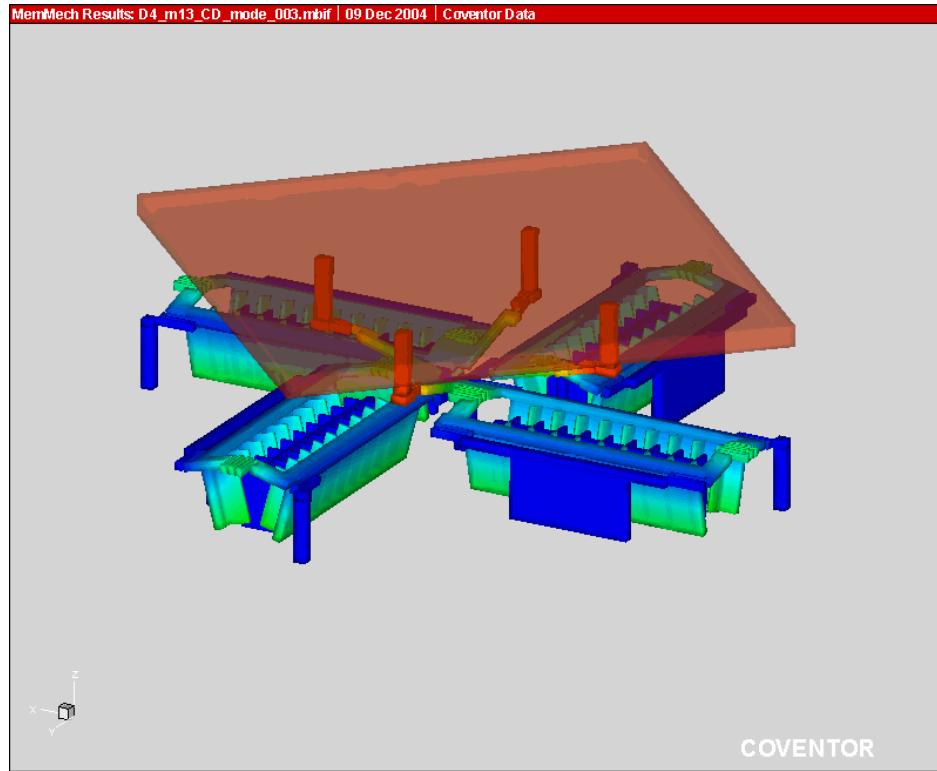
Linear

2D



Design principle

Dual, in-plane, rotational comb-drives



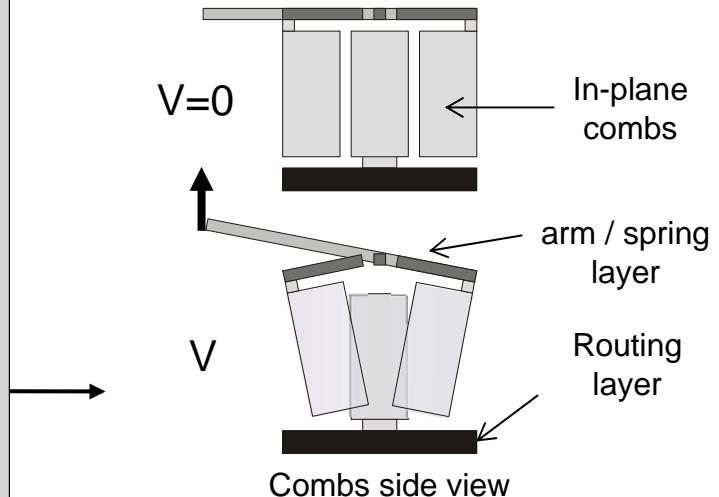
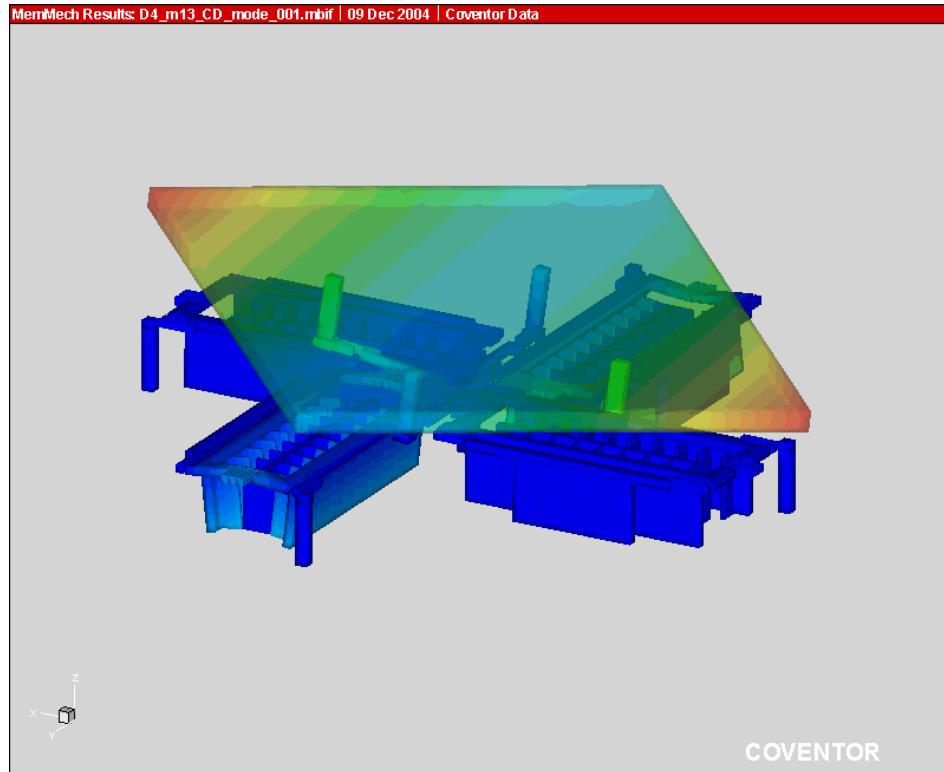
- 4 actuators in parallel
- One control signal per actuator
- 2 comb drives per actuator

Piston motion results from
two opposite actuators or all four
actuators together



Design principle

Dual, in-plane, rotational comb-drives

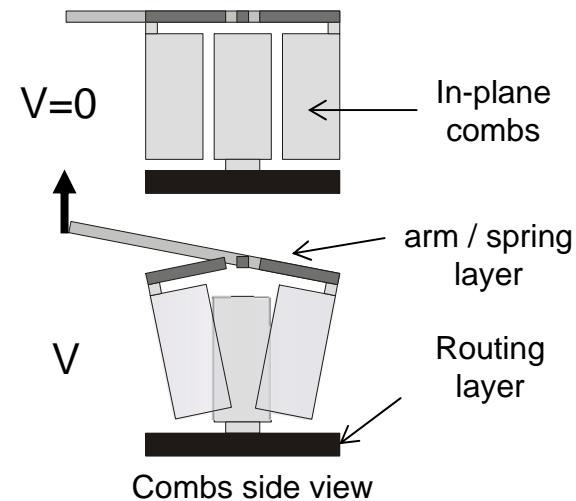
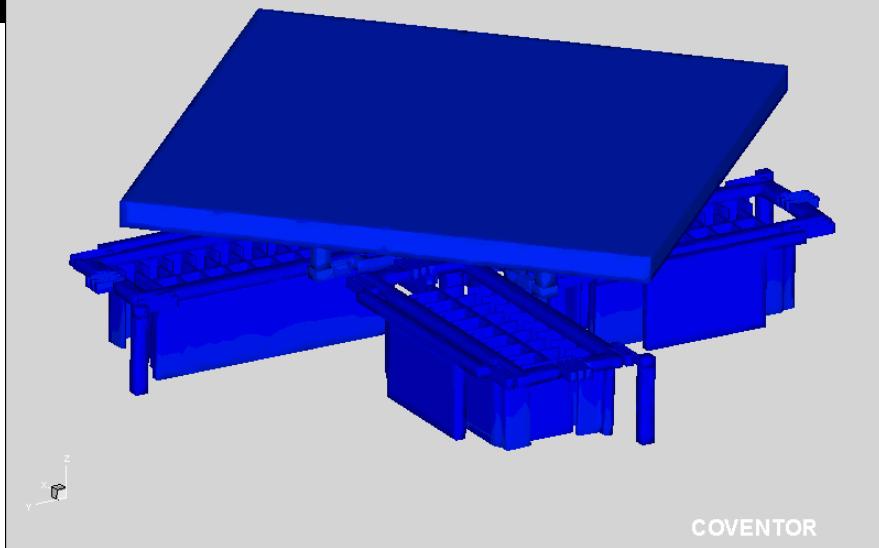


- 4 actuators in parallel
- One control signal per actuator
- 2 comb drives per actuator

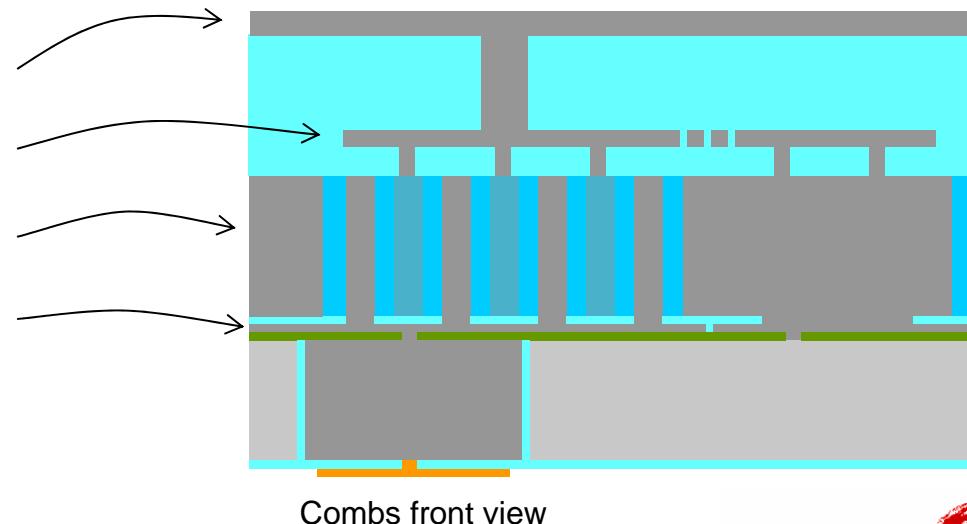
Tilt motion results from
**single actuators or two adjacent
actuators together**



Design principle and fabrication



1-2 μm	PolySi-3 Mirror	CD .5 μm
1-2 μm	PolySi-2 Spring/Arm	CD .5 μm
6-12 μm	PolySi-1 Combs	CD .5 μm
2.5 μm	Routing (PolySi-0 +)	CD .5 μm
2-4.5 μm	Sacrificial layers (each)	



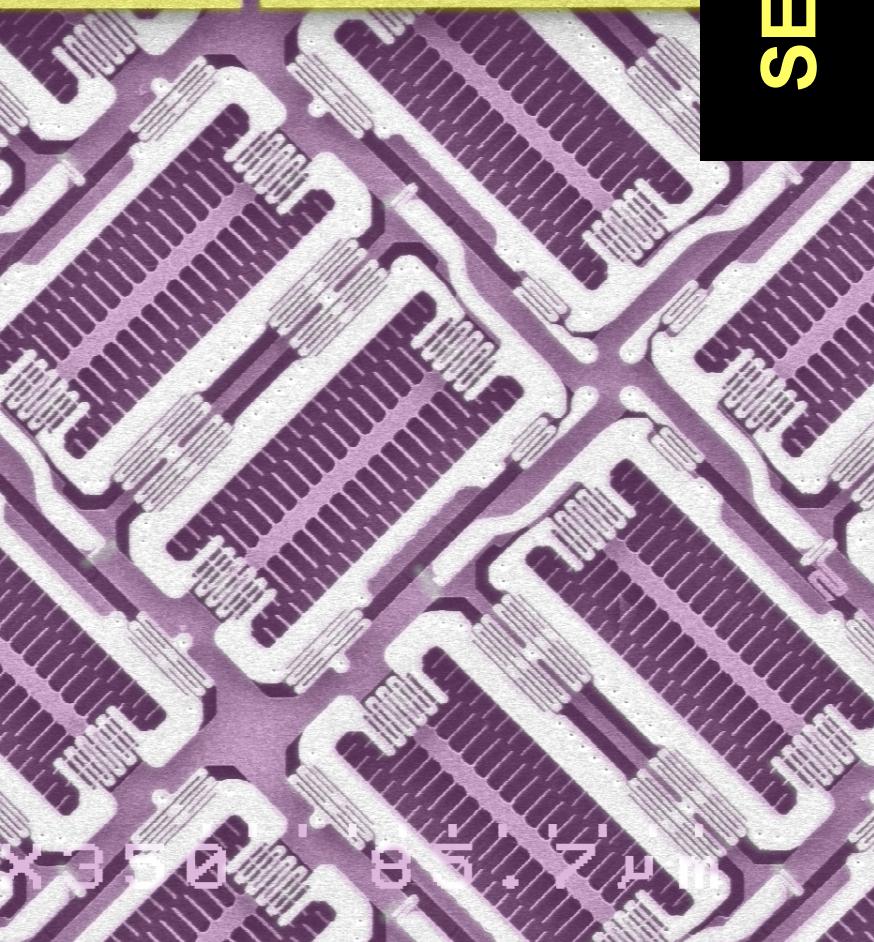
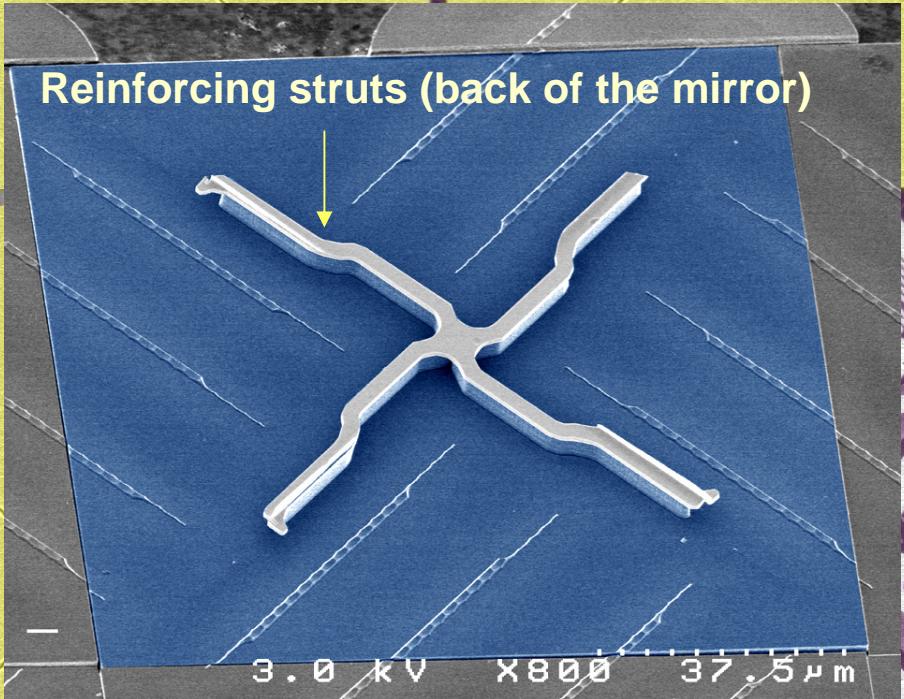
Total: 17-28 μm
with \approx 100nm registration accuracy between all layers



SEM Images

120 μ m

10 mask levels 248nm
4X stepper lithography



Monolithic Mirror

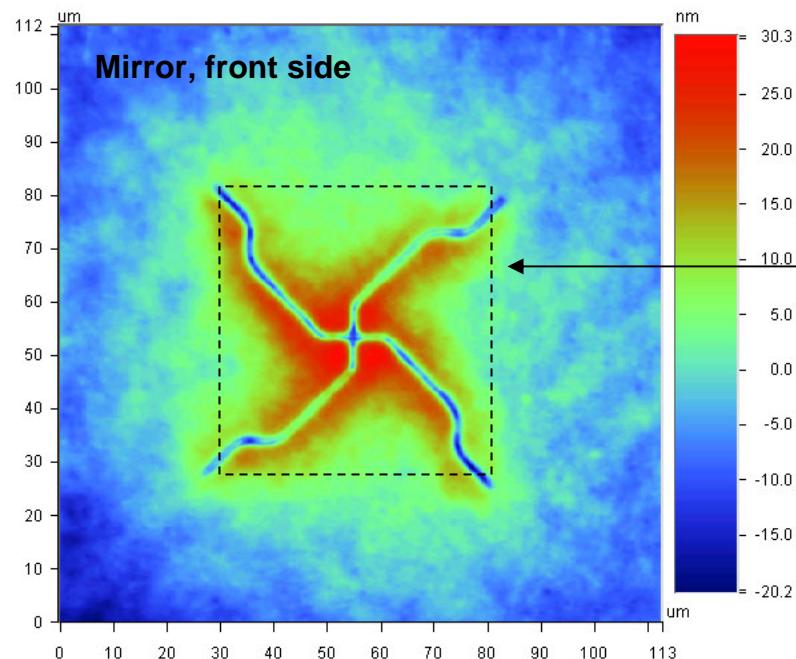
Surface Statistics:
Ra: 5.76 nm
Rq: 7.58 nm
Rz: 47.69 nm
Rt: 50.43 nm

Set-up Parameters:

Size: 553 X 469
Sampling: 204.39 nm

Processed Options:

Terms Removed:
Tilt
Filtering:
None



Strut-reinforced, 1.5 μ m thick mirror with 40Å Ti / 400Å Au

Even with this deposition/polishing artifact the **peak to valley variation is ~50nm**

Excluding that region and the overall curvature the **RMS roughness is ~1.85nm**

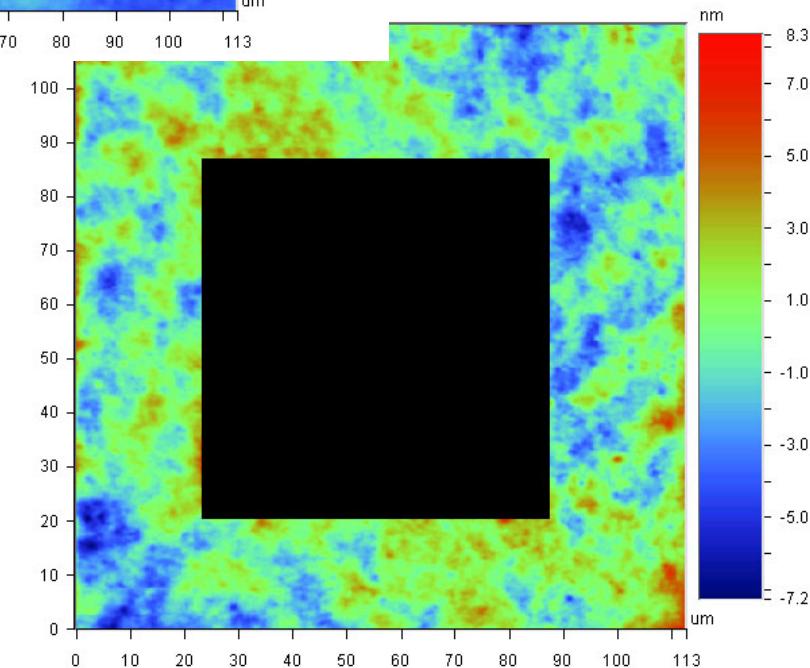
Surface Statistics:
Ra: 1.48 nm
Rq: 1.84 nm
Rz: 13.10 nm
Rt: 15.59 nm

Set-up Parameters:

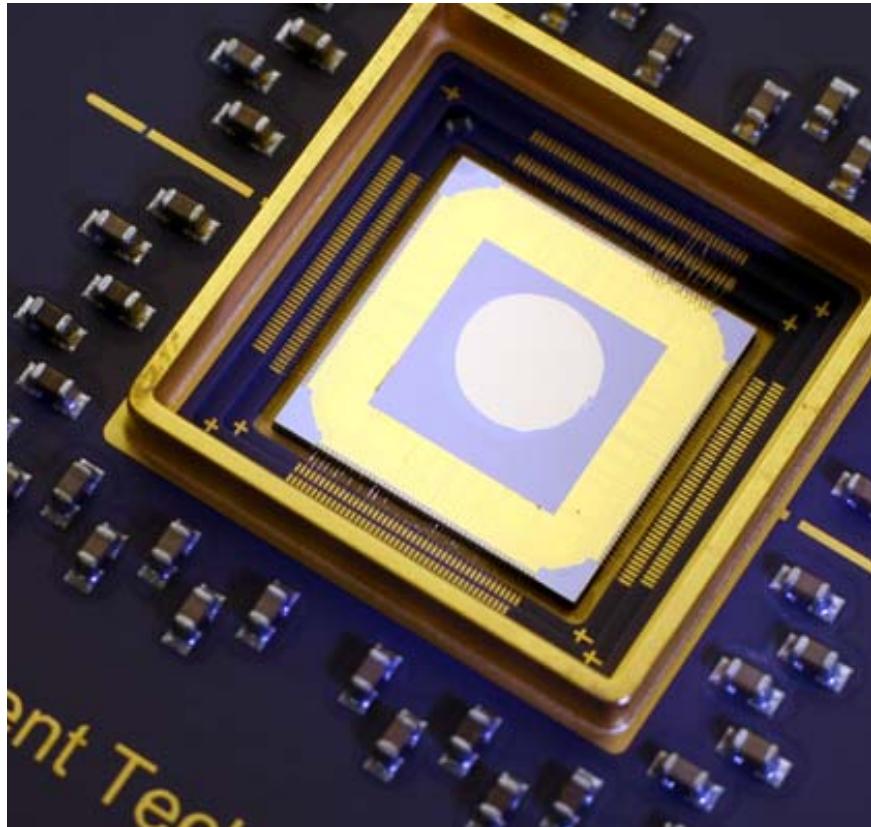
Size: 553 X 469
Sampling: 204.39 nm

Processed Options:

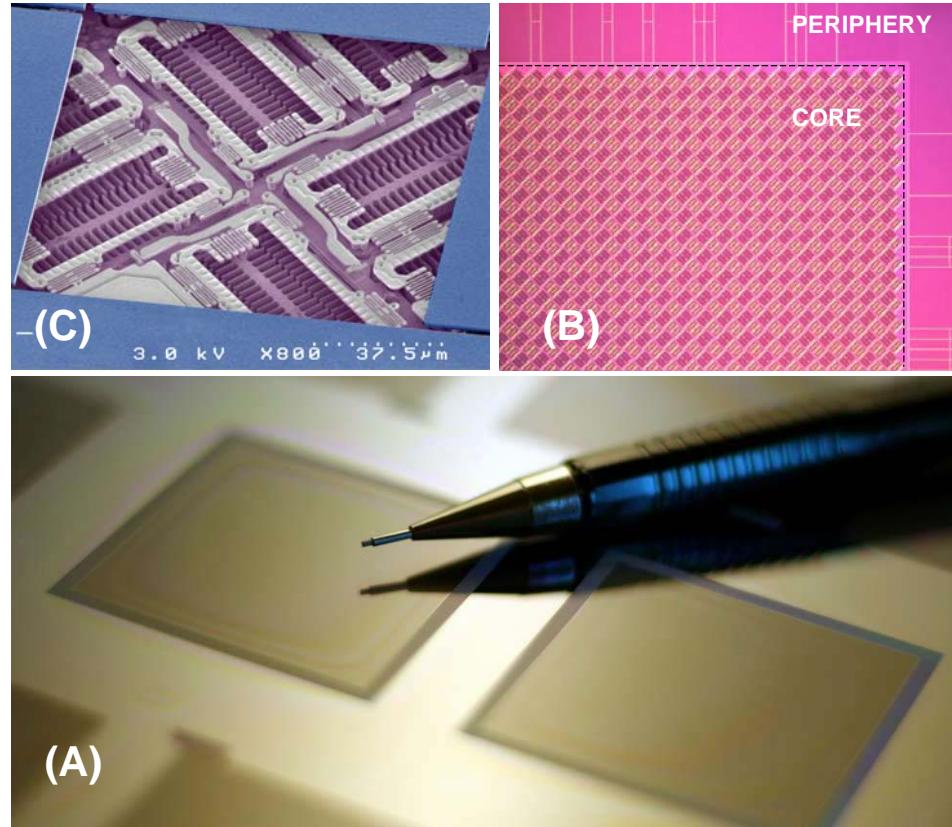
Terms Removed:
Curvature & Tilt
Filtering:
None



Test Vehicle



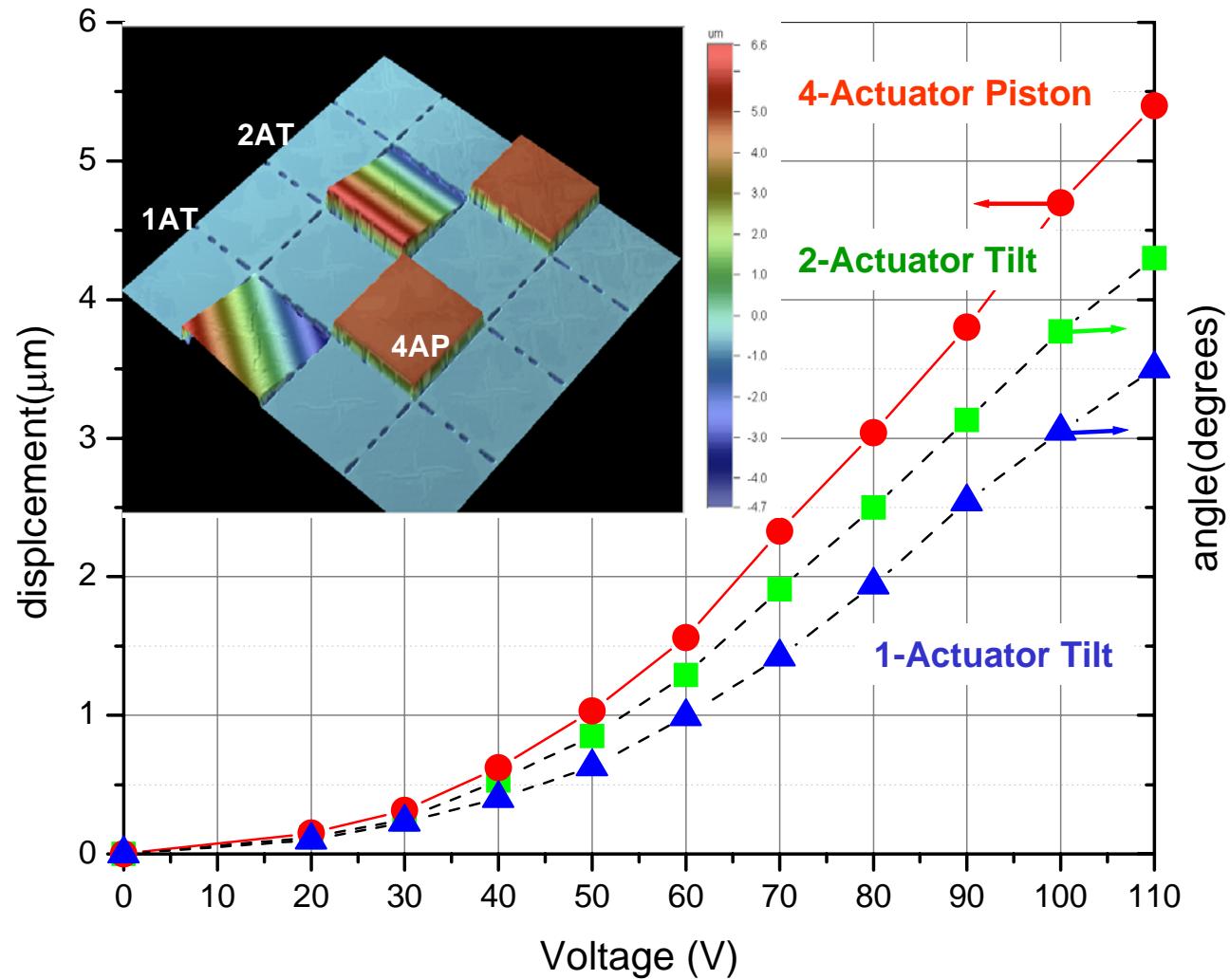
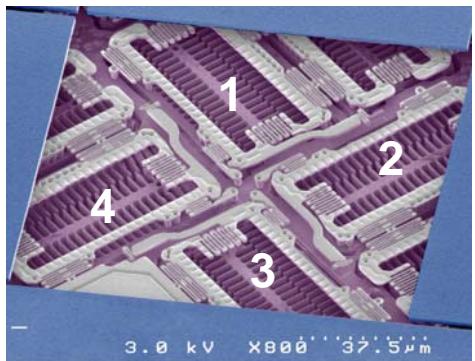
Packaged 64x64



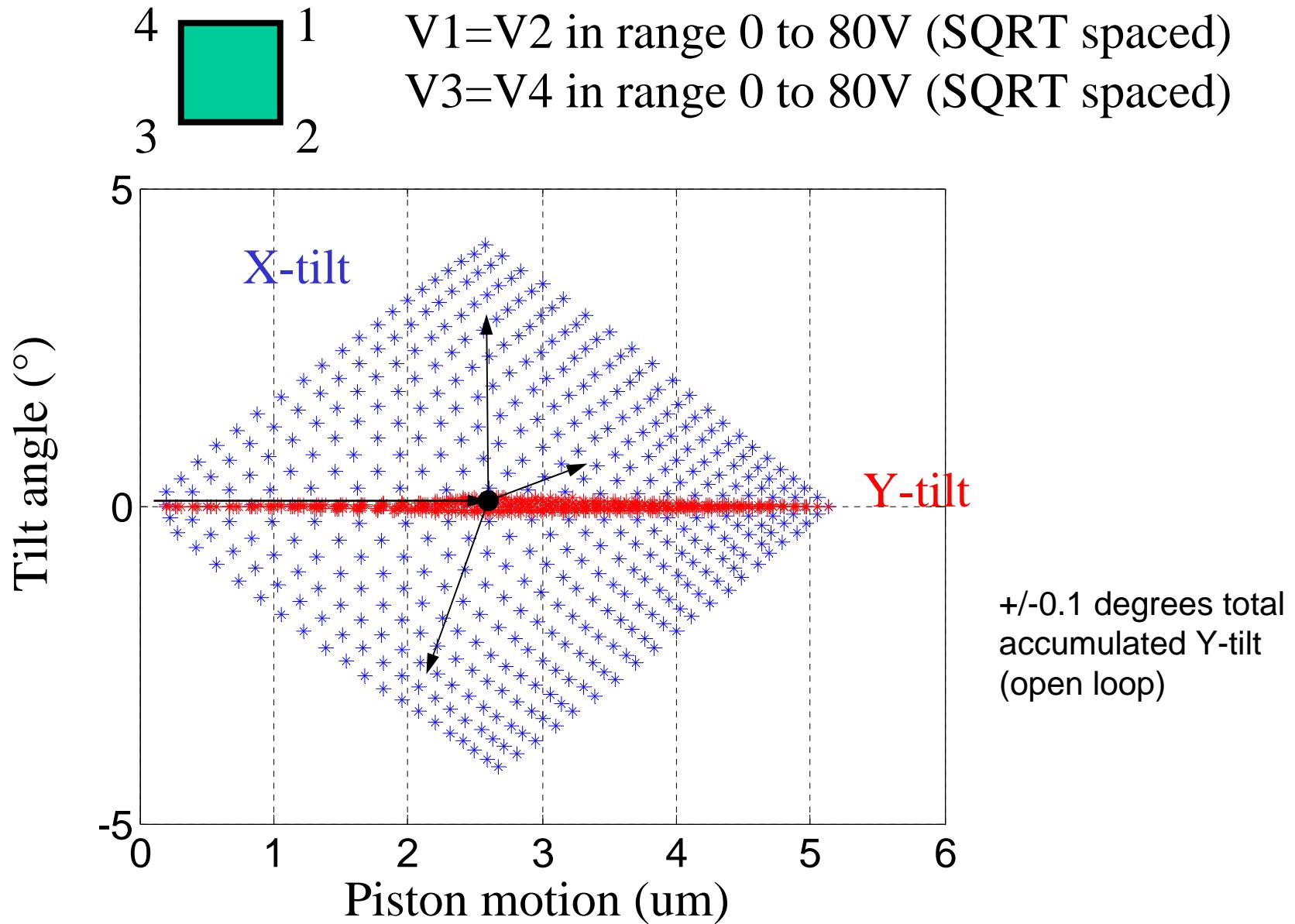
256x256 on 8" wafer



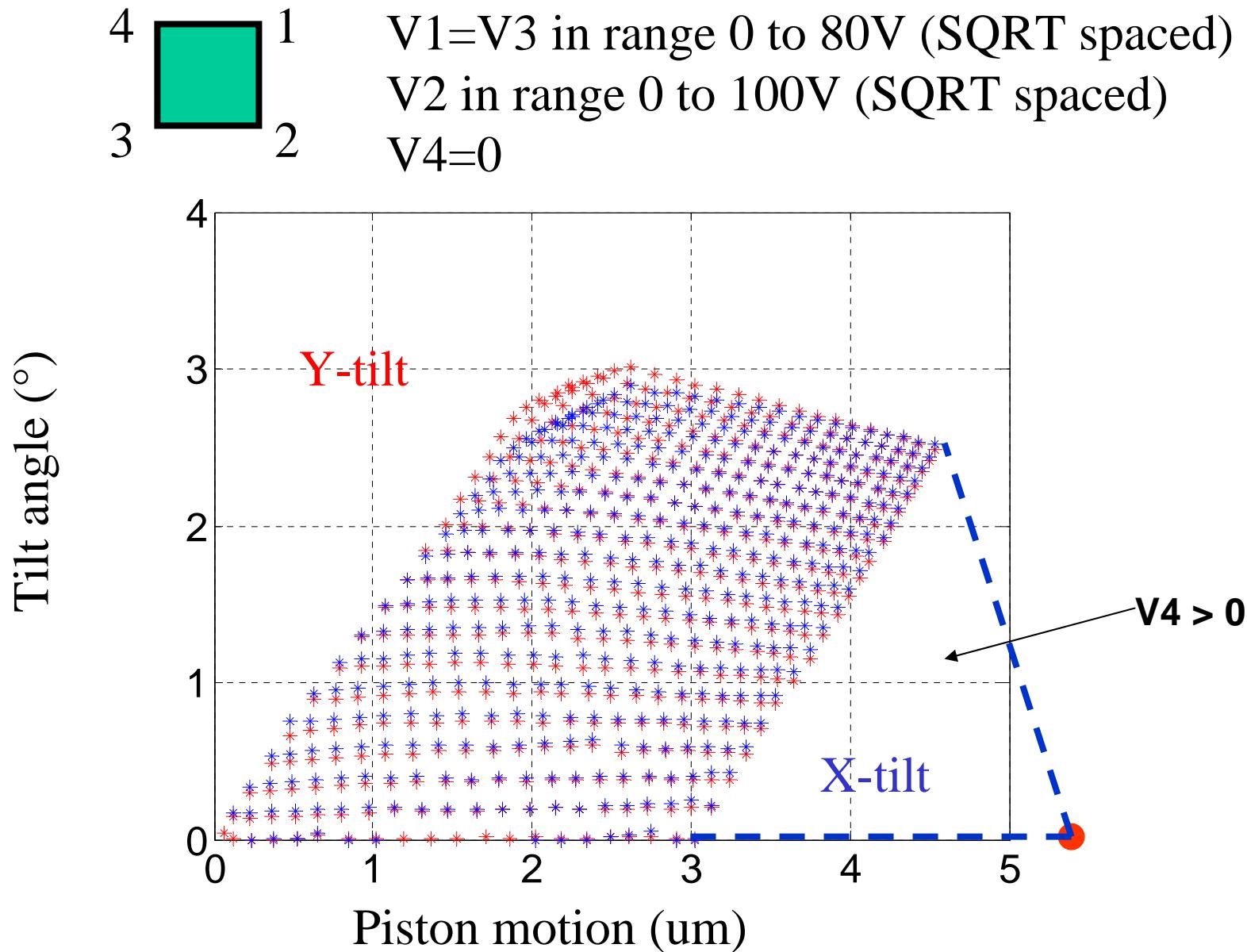
Mechanical Response: Angle-Piston vs. Voltage



Combined X-tilt and Piston:



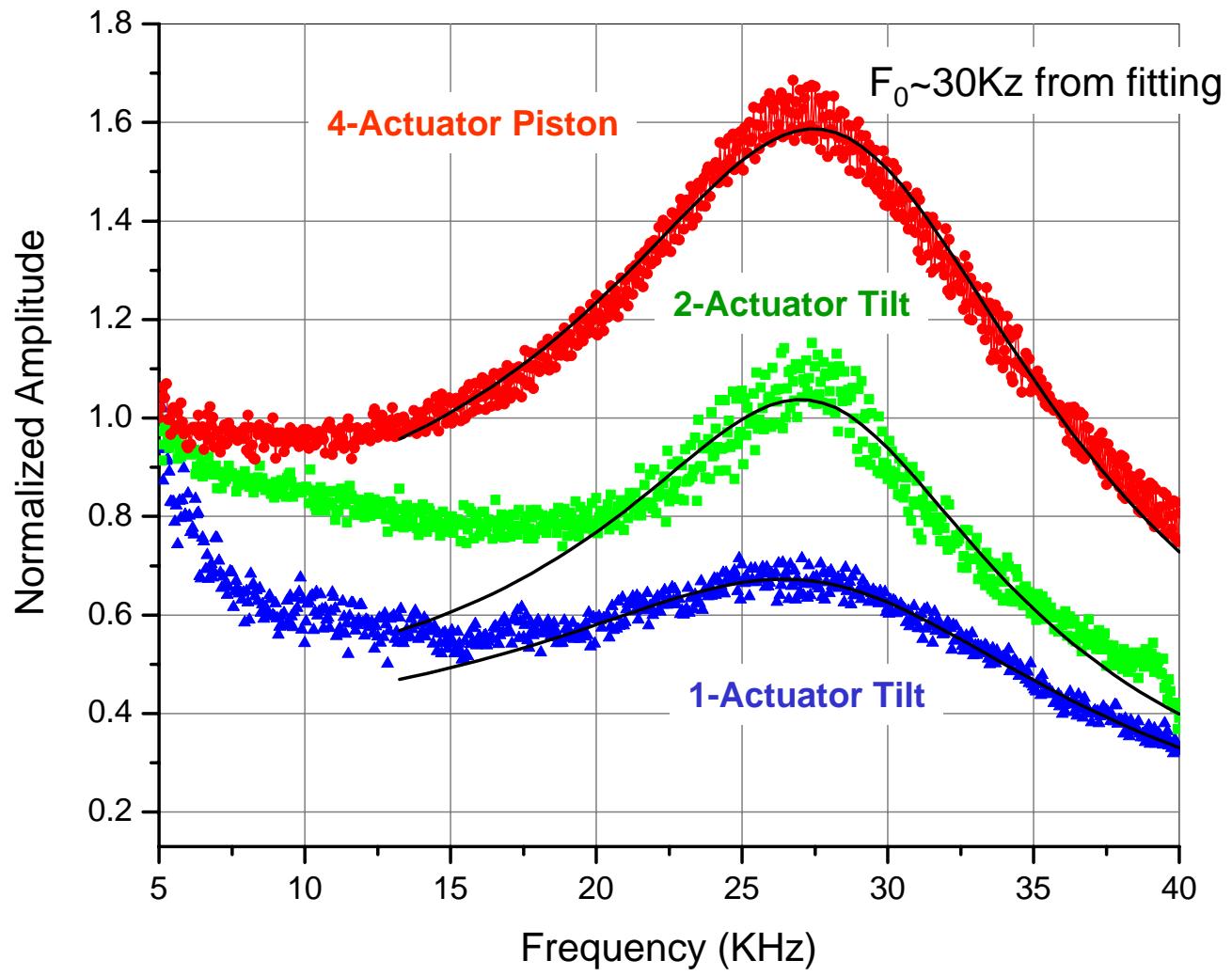
Combined Diagonal Tilt and Piston:



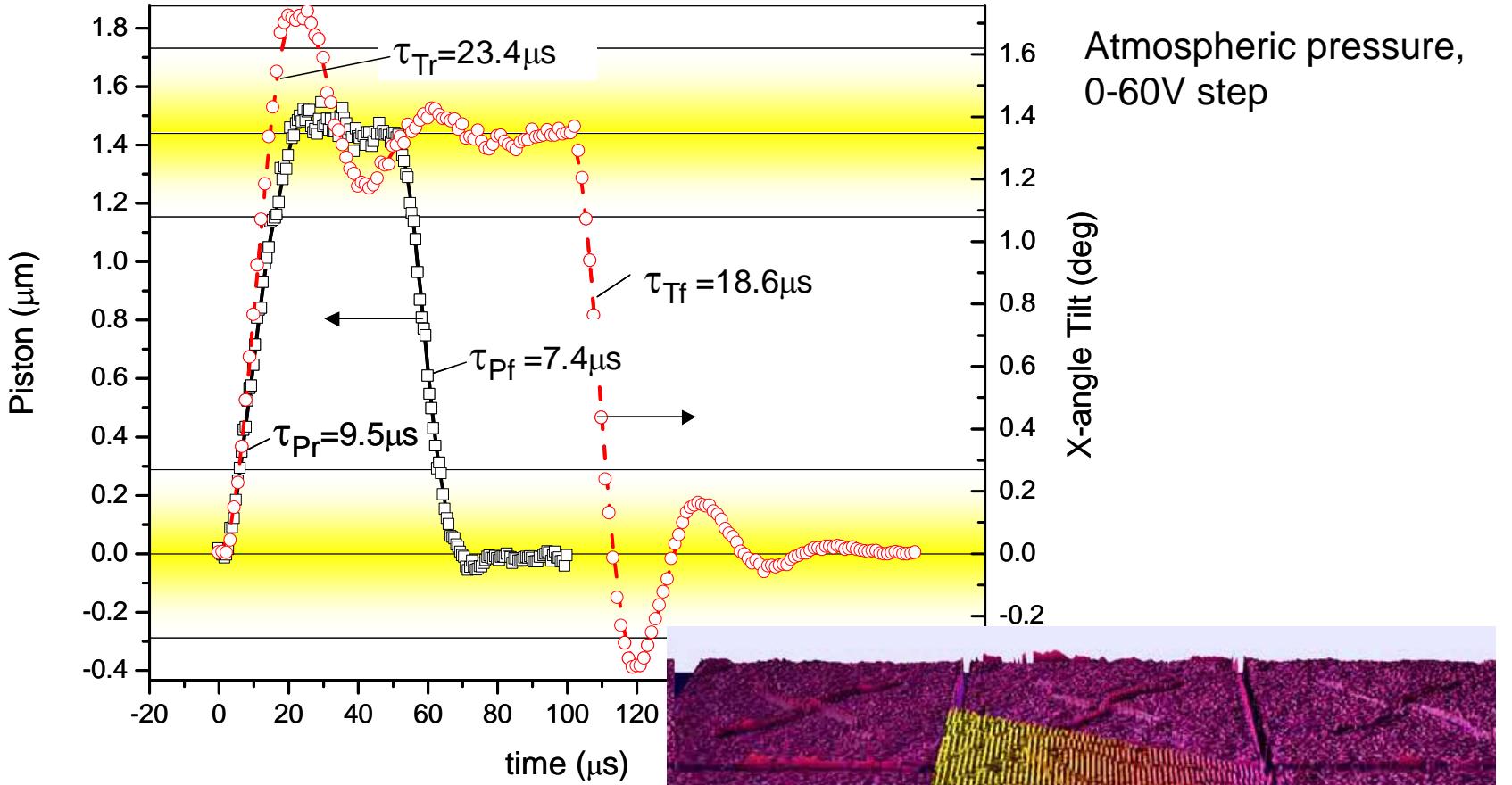
Mechanical Response: Resonance

Simulated Resonance frequencies in Vacuum

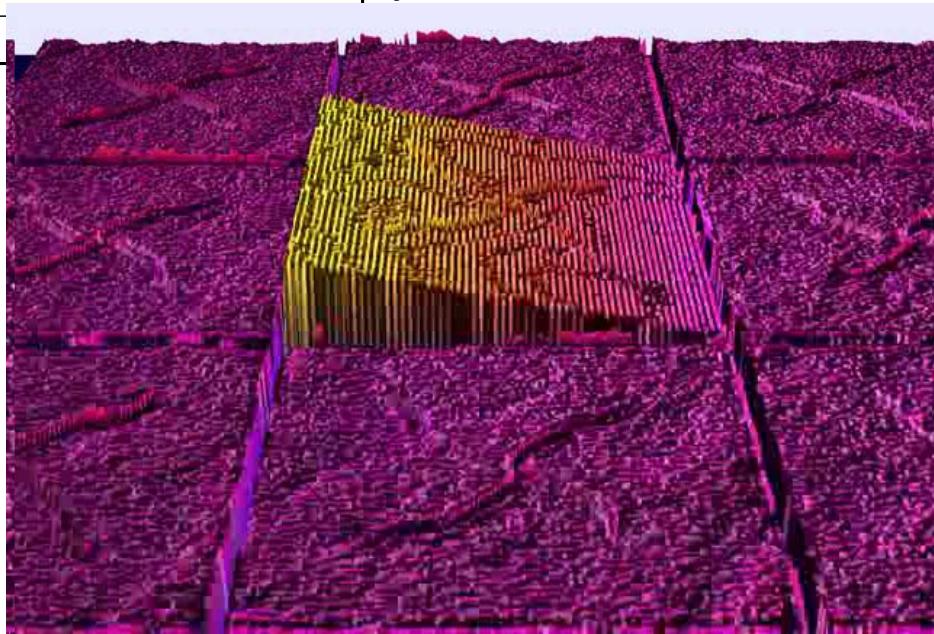
Mode	F_0
Tilt 1	29.6KHz
Tilt 2	29.6KHz
Piston	30.9KHz
next mode	140KHz



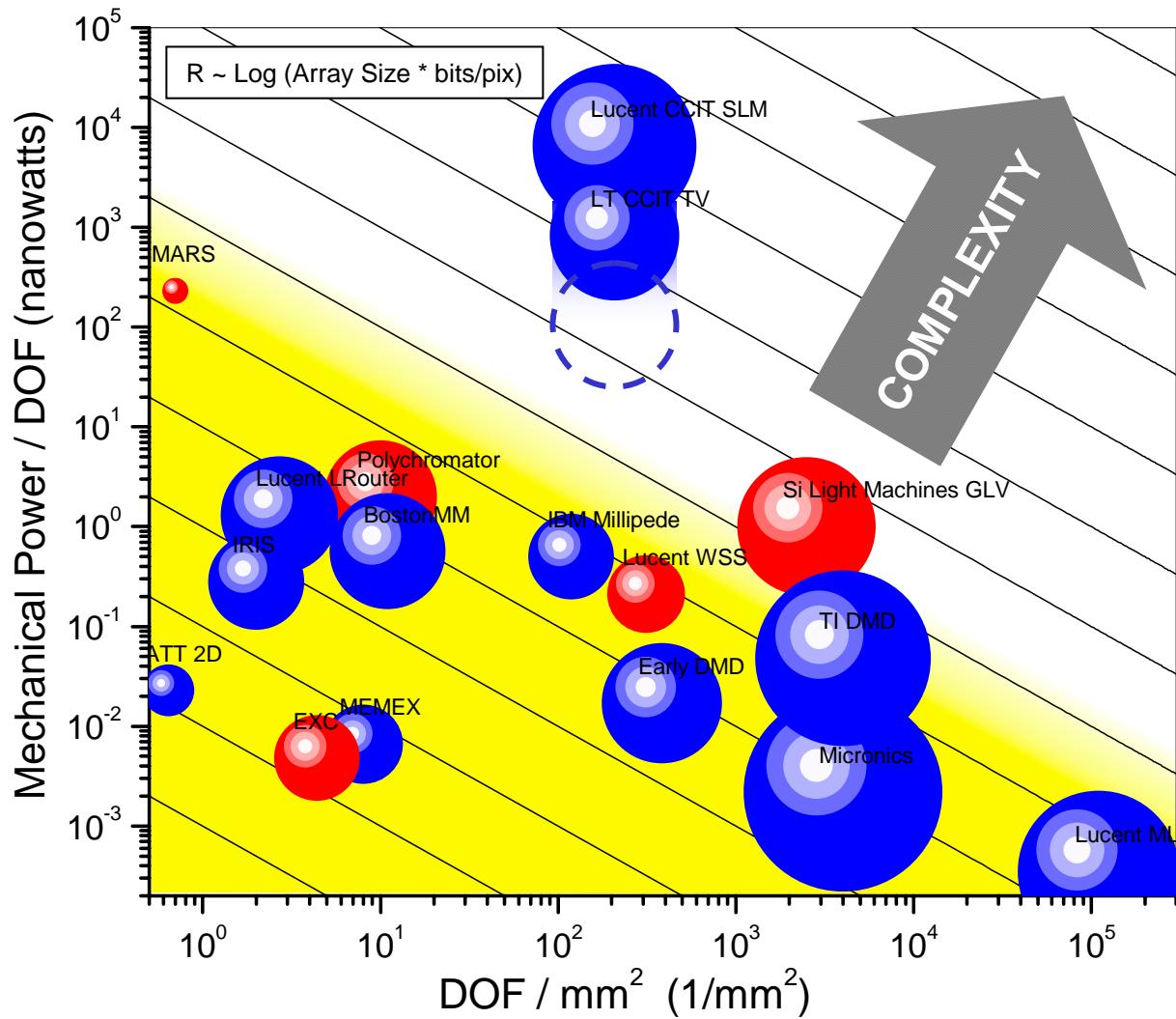
Mechanical Response: Step Function



Interferometer
stroboscopic
measurement
Video frame rate:
6000X slower than
actual motion



Summary



We have Implemented
high-force actuator
design in a 10-
lithography-step MEMS
process

$5.4\mu\text{m}$, $10\mu\text{s}$ piston
 4.3° , $20\mu\text{s}$ tilt

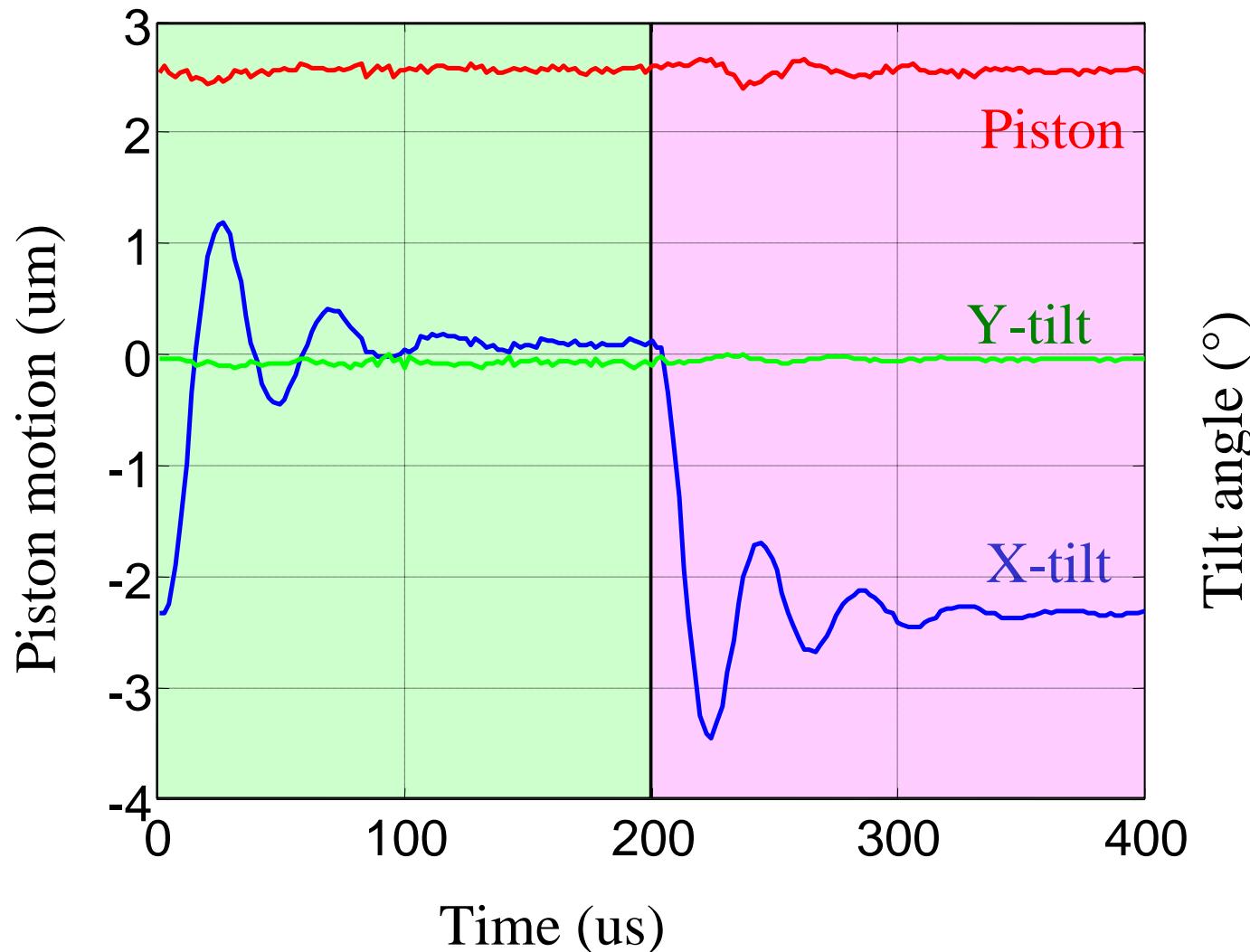
MEMS fabrication
approach scalable to
 256^2 and beyond

Integration-ready with
high-voltage electronics

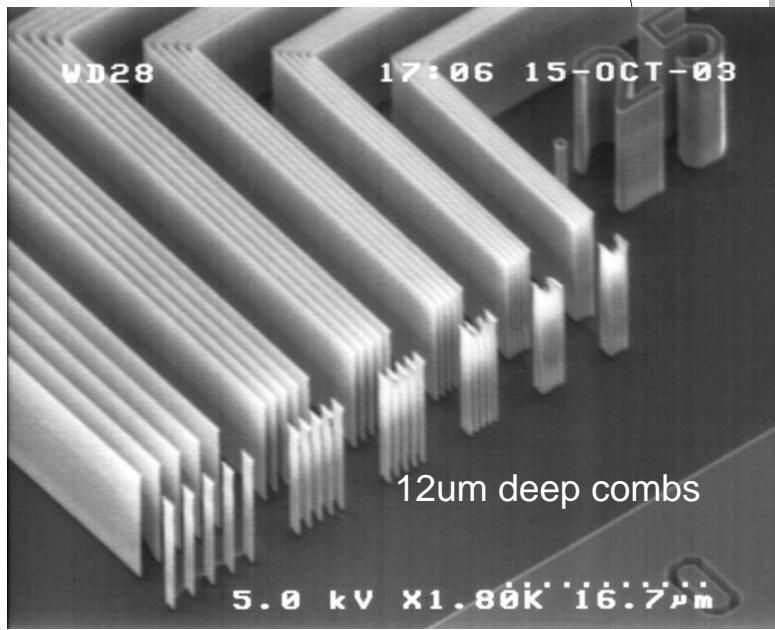
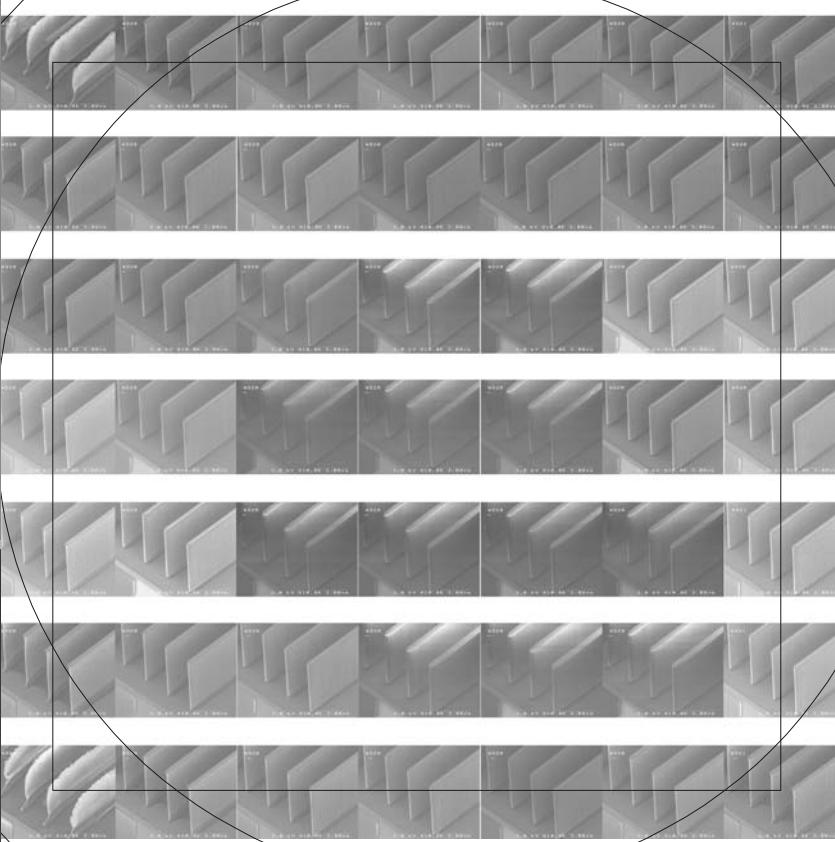
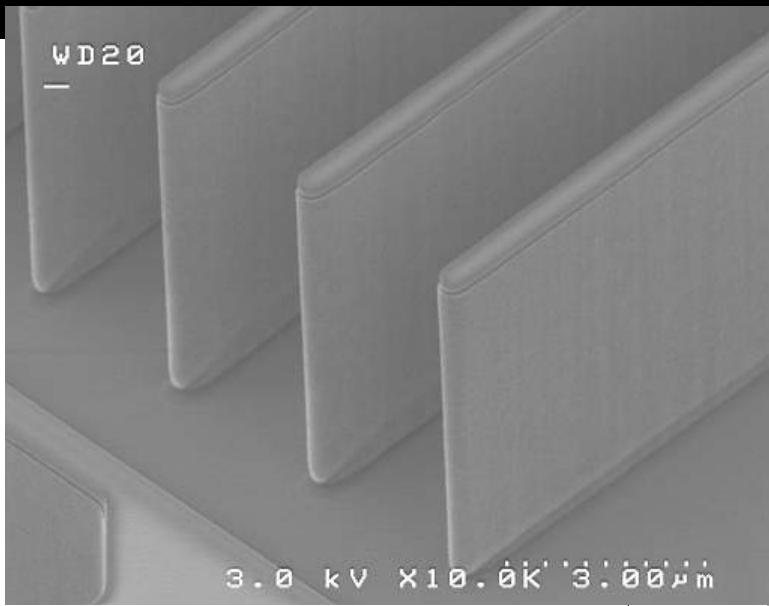
**Design and
fabrication tour de
force**



Pure Tilt Dynamics



Future: faster response



- Deeper combs, stiffer springs
- Damping Tuning
- Tailor for different applications within this platform
- Continue to work on integration / packaging

